ACT-09-12, MIFPA-12-23

Correlating LHCb $B_s^0 \to \mu^+\mu^-$ Results with the ATLAS-CMS Multijet Supersymmetry Search

Tianjun Li,[1,2] James A. Maxin,[2] Dimitri V. Nanopoulos,[2,3,4] and Joel W. Walker[5]

[1] *State Key Laboratory of Theoretical Physics and Kavli Institute for Theoretical Physics China (KITPC), Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, P. R. China*
[2] *George P. and Cynthia W. Mitchell Institute for Fundamental Physics and Astronomy, Texas A&M University, College Station, TX 77843, USA*
[3] *Astroparticle Physics Group, Houston Advanced Research Center (HARC), Mitchell Campus, Woodlands, TX 77381, USA*
[4] *Academy of Athens, Division of Natural Sciences, 28 Panepistimiou Avenue, Athens 10679, Greece*
[5] *Department of Physics, Sam Houston State University, Huntsville, TX 77341, USA*

We show that the No-Scale Flipped $SU(5)$ construction is transparently consistent with recent LHCb results for $B_S^0 \to \mu^+\mu^-$ decays, due primarily to suppression from the rather small value of $\tan\beta \sim 20$ that is globally enforced across the model space. This fact should be interpreted in conjunction with the demonstrated evasion of mass limits from the ATLAS and CMS SUSY searches and the more important potential explanation of small observed excesses in the multijet data. The No-Scale Flipped $SU(5)$ benchmark model that best fits these excesses has a gaugino mass scale of $M_{1/2} = 708$ GeV, which drives masses for the bino-dominated LSP $m_{\widetilde{\chi}_1^0} = 143.4$ GeV, light stop $m_{\widetilde{t}_1} = 786$ GeV, gluino $m_{\widetilde{g}} = 952$ GeV, and heavy squark $m_{\widetilde{u}_L} = 1490$ GeV. The corresponding total prediction for the rare B-decay of $Br(B_S^0 \to \mu^+\mu^-) = 3.5\ \times 10^{-9}$ suggests that the SUSY contribution may indeed be much smaller than that expected from the Standard Model in this framework, fitting quite comfortably within the very tightly constrained region remaining viable after the most recent LHCb measurements.

PACS numbers: 11.10.Kk, 11.25.Mj, 11.25.-w, 12.60.Jv

Upon completion of several ATLAS and CMS 5 fb^{-1} supersymmetry (SUSY) searches of the total 2011 LHC data harvest [1–6], interesting correlations [7, 8] began to emerge between event signatures registered by the collaborations and a high-energy model framework known as $\mathcal{F}$-$SU(5)$ (See Refs. [7–17] and all references therein), which combines the No-Scale Flipped $SU(5)$ grand unified theory (GUT) with extra vector-like particles (flippons). Despite an absence of any conclusive signs of supersymmetry thus far at the LHC, we presented the case [7, 8] that those studies with curious event excesses over the expected Standard Model (SM) background all implicate a consistent narrow swath of the $\mathcal{F}$-$SU(5)$ SUSY mass scale, subsequent to an embedding of the collaboration selection strategies into that construction. The largest significance in signal strength was observed in the ATLAS multijet realm [1, 2], permitting determination of prospective best fit SUSY masses for a bino-dominated LSP $m_{\widetilde{\chi}_1^0} = 143.4$ GeV, the light stop $m_{\widetilde{t}_1} = 786$ GeV, gluino $m_{\widetilde{g}} = 952$ GeV, and heavy squark $m_{\widetilde{u}_L} = 1490$ GeV [7]. Intriguingly, the most meaningful signal strength within data reported by CMS also prevailed in the multijet domain [6]. Given that the $\mathcal{F}$-$SU(5)$ supersymmetric event landscape at the LHC is anticipated to be dominated by multijets [9, 11–15], the cumulative fidelity of the proffered explanation would be enhanced by the systematic preference of a budding phase of SUSY event production for the multijet search space.

These mounting correlations compel the undertaking of fresh consistency checks against recently improved B-decay constraints, specifically those from the flavour changing neutral current process $B_S^0 \to \mu^+\mu^-$ [18], where the initial quark content is $(s, \overline{b})$. We take the branching ratio from Refs. [19, 20], which we write in the form

$$\mathcal{B}r(B_s^0 \to \mu^+\mu^-) = \frac{2\tau_B m_B^5}{64\pi} f_{B_s}^2 \sqrt{1 - \frac{4m_\mu^2}{m_B^2}} \left[\left(1 - \frac{4m_\mu^2}{m_B^2}\right)\left|\frac{(C_S - C_S')}{(m_b + m_s)}\right|^2 + \left|\frac{(C_P - C_P')}{(m_b + m_s)} + 2\frac{m_\mu}{m_{B_s}^2}(C_A - C_A')\right|^2\right] \qquad (1)$$

where f_{B_s} is the B_s decay constant, m_B is the B meson mass, and τ_B is the mean life. The factors C_A, C_A' are primarily determined by the Standard Model diagrams, whereas C_S, C_S', C_P, C_P' include the SUSY loop contributions resulting from diagrams relating to particles such as, for example, the light stop, chargino, sneutrino, and Higgs bosons.

The LHCb has undertaken measurements of rare B-decay processes with unprecedented precision, establishing an upper bound on the branching ratio of the $B_S^0 \to \mu^+\mu^-$ process of $Br(B_S^0 \to \mu^+\mu^-) < 4.5(3.8) \times 10^{-9}$ at the 95% (90%) confidence level [21]. With well-defined predictions in the Standard Model of $Br(B_S^0 \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$ [22, 23], where the loop-level process employs a virtual W-boson to transmute the quark content and facilitate a $t\bar{t} \to Z^0$ fusion event, severe constraints may potentially be placed upon the viable parameter spaces of any candidate SUSY framework [24]. In particular, the allowed SUSY contribution to these rare B-decays is in a state of rapid contraction following recent CMS [25] and LHCb [21] high-precision measurements. Simultaneously surviving the swiftly escalating ATLAS and CMS SUSY mass spectrum constraints while making only compulsorily insubstantial SUSY contributions to $B_S^0 \to \mu^+\mu^-$ is truly becoming a fine needle to thread.

The vector-like flippon multiplets will contribute to the B rare decays to $\mu^+\mu^-$ since they will contribute to the two axial-current operators O_{10} and O'_{10} from the mixings with the SM fermions [26]. Thus, the process $B_s^0 \to \mu^+\mu^-$ will give strong constraints on the tree-level flavour changing neutral current effects [26]. Note that without flippon contributions, we have $Br(B_s^0 \to \mu^+\mu^-) = 3.5 \times 10^{-9}$ for the benchmark points of Ref. [7, 16, 17]. Thus, we must suppress the flippon contributions by some combined effect of i) the natural heaviness of the multiplets, around a few times the TeV scale, and ii) an assumption that the mixings between the flippons and the SM fermions are relatively small.

The $\mathcal{F}$-$SU(5)$ experimentally viable model space perimeter is shaped by application of the bare-minimal experimental constraints defined in Ref. [10], which is defined by simultaneous consistency with i) the dynamically established high-scale boundary conditions M_0=A=B_μ=0 of No-Scale Supergravity, ii) radiative electroweak symmetry breaking, iii) precision LEP constraints on the lightest CP-even Higgs boson m_h [27, 28] and other light SUSY chargino and neutralino mass content, iv) a top-quark mass 172.2 GeV $\leq m_{\rm t} \leq$ 174.4 GeV, and v) a single, neutral supersymmetric cold dark-matter (CDM) candidate providing a relic density within the 7-year WMAP limits $0.1088 \leq \Omega_{\rm CDM} \leq 0.1158$ [29]. These constraints represent those experiments that are regarded as exhibiting the greatest stability, with conclusions possessing the broadest acceptance. Moreover, we superpose on the model space derived out of the bare-minimal constraints upper and lower boundaries on the light Higgs boson mass of $124 \leq m_h \leq 126$ GeV, reflecting the recent 5σ over background discovery observed by ATLAS [30], CMS [31], and CDF/DØ [32]. The flippons fill an essential role in this context by coupling to the Higgs boson and naturally generating a 3–4 GeV upward shift [14] to m_h, facilitating a physical Higgs boson mass in excellent conformity with the observations.

The $\mathcal{F}$-$SU(5)$ model space remaining after implementation of the bare-minimal constraints plus the 124–126 GeV Higgs mass limits is illustrated in Figure (1) as a function of the gaugino mass $M_{1/2}$ and flippon mass M_V, encompassing a narrow sliver confined to the region of $400 \leq M_{1/2} \leq 900$ GeV, $19.4 \leq \tan\beta \leq 23$, and $950 \leq M_V \leq 6000$ GeV. The lowermost boundary at $M_{1/2}$ = 400 GeV is demanded by the LEP constraints, while the uppermost boundary at $M_{1/2} = 900$ GeV is a consequence of a charged stau LSP exclusion around $\tan\beta \simeq 23$. The SUSY particle masses and B-decay branching ratios are calculated with `MicrOMEGAs 2.1` [33], applying a proprietary modification of the `SuSpect 2.34` [34] codebase to run the flippon-enhanced renormalization group equations (RGEs).

We inset into Figure (1) the multi-axis cumulative χ^2 fitting of Ref. [7], linked to the horizontal axis $M_{1/2}$. Clearly illustrated is the well of the χ^2 at $M_{1/2} = 708$ GeV, representing the best fit SUSY mass to those ATLAS SUSY searches demonstrating a signal significance of $S/\sqrt{B+1} > 2$. The smoothly graded contours of color depict the value of $Br(B_S^0 \to \mu^+\mu^-)$. The rate for the SUSY contribution to $B_S^0 \to \mu^+\mu^-$ is proportional to the sixth power of $\tan\beta$, and due to the fact that $\mathcal{F}$-$SU(5)$ globally enforces a relatively small value of $19.4 \leq \tan\beta \leq 23$, the $\mathcal{F}$-$SU(5)$ model space within the median fit of the χ^2 well resides at $Br(B_S^0 \to \mu^+\mu^-) \leq 3.6 \times 10^{-9}$, with $Br(B_S^0 \to \mu^+\mu^-) = 3.5 \times 10^{-9}$ at $M_{1/2} = 708$ GeV, both comfortably in accordance with the very tight LHCb constraint of $Br(B_S^0 \to \mu^+\mu^-) < 4.5$ (3.8) $\times 10^{-9}$ at the 95% (90%) confidence level. So indeed, it seems No-Scale $\mathcal{F}$-$SU(5)$ has successfully threaded the needle of ATLAS and CMS SUSY mass constraints in parallel with an exceptionally small SUSY contribution to $B_S^0 \to \mu^+\mu^-$, the combination deemed to be so intractable for the typical SUSY framework.

Conclusions–The LHC has amassed a total of 5 fb^{-1} of integrated luminosity at $\sqrt{s} = 7$ TeV through the close of 2011. Consequently, the entire landscape of supersymmetric models has dwindled considerably, as the increasing SUSY mass limits have invalidated many prior contenders. For those few high-energy frameworks left standing, the unprecedented precision of the LHCb measurements of the B-decay process $B_S^0 \to \mu^+\mu^-$ could have been the final blow. In spite of this dim outlook, we showed here that No-Scale $\mathcal{F}$-$SU(5)$, which has already demonstrated the capacity to evade the encroaching ATLAS and CMS SUSY mass constraints while perhaps moreover *explaining* the origin of small excesses in the 5 fb^{-1} multijet data observations, is in fact further bolstered by the new LHCb results. Due to the relatively small globally allowed range of $19.4 \leq \tan\beta \leq 23$, the $\mathcal{F}$-$SU(5)$ SUSY contribution to $Br(B_S^0 \to \mu^+\mu^-)$, which is proportional to the sixth power of $\tan\beta$, is much smaller than the effect expected within the Standard Model. Thus, a large value of $Br(B_S^0 \to \mu^+\mu^-)$ could have dealt a very damaging hit to $\mathcal{F}$-$SU(5)$. On the contrary, the now apparent insubstantial SUSY contribution measured at the LHCb is very consistent with that required in a No-Scale $\mathcal{F}$-$SU(5)$ universe. Indeed, we demonstrated that the SUSY mass spectrum of an LSP $m_{\widetilde{\chi}_1^0} = 143.4$ GeV, light stop $m_{\widetilde{t}_1} = 786$ GeV, gluino $m_{\widetilde{g}} = 952$ GeV, and heavy squark $m_{\widetilde{u}_L} = 1490$ GeV, which can efficiently explain the ATLAS multijet data observation excesses, exhibits a B-decay of $Br(B_S^0 \to \mu^+\mu^-) = 3.5 \times 10^{-9}$, well within the quite constrained LHCb result of $Br(B_S^0 \to \mu^+\mu^-) < 4.5$ (3.8) $\times 10^{-9}$ at the 95% (90%) confidence level. Whether nature is herself truly described by No-Scale $\mathcal{F}$-$SU(5)$ remains, for now, be-

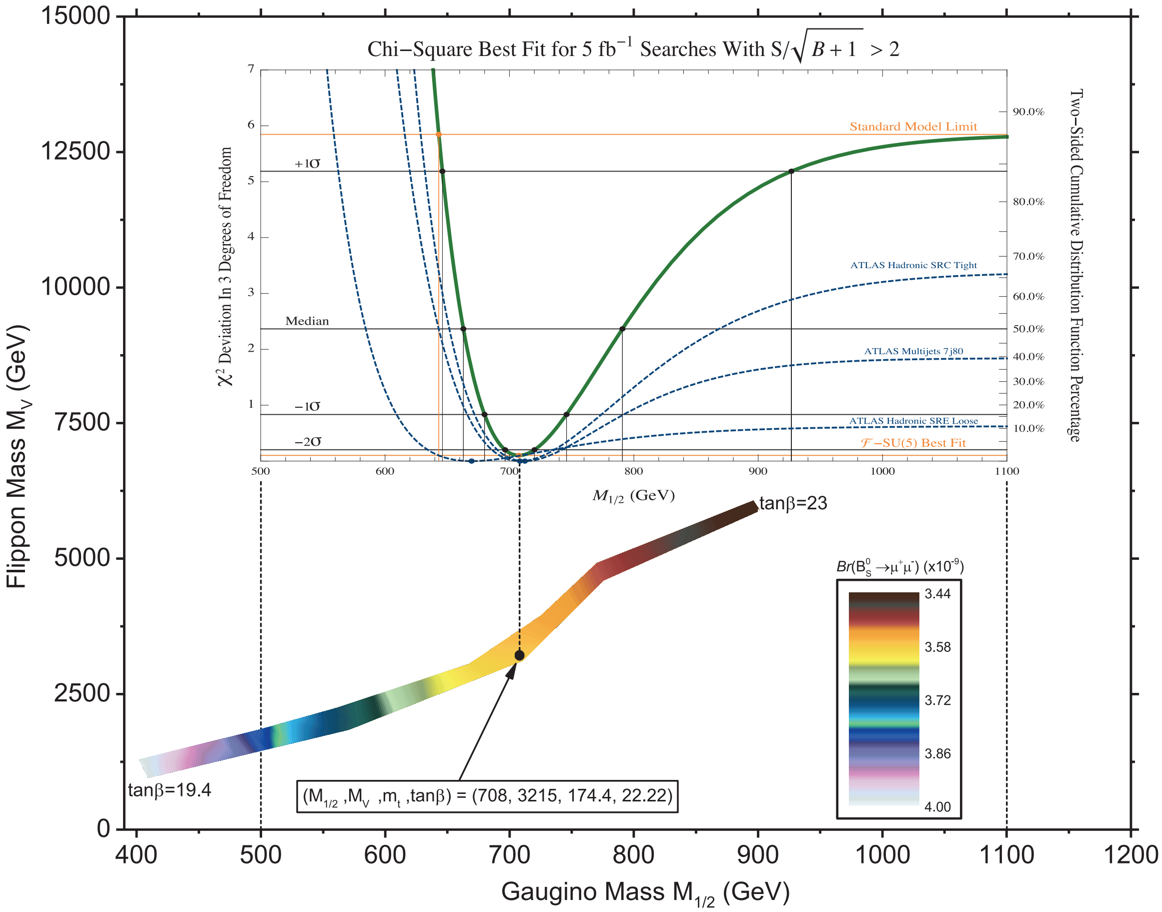

FIG. 1: We depict the experimentally viable parameter space of No-Scale $\mathcal{F}$-$SU(5)$ as a function of the gaugino mass $M_{1/2}$ and flippon mass M_V. The surviving model space after application of the bare-minimal constraints of Ref. [10] and Higgs boson mass calculations of Ref. [14] is illustrated by the narrow strip with the smoothly contoured color gradient. The gradient represents the total branching ratio (SM+SUSY) of the B-decay process $B^0_S \to \mu^+\mu^-$, numerically scaled as displayed in the color bar legend. The inset diagram (with linked horizontal scale) is the multi-axis cumulative χ^2 fitting of Ref. [7], depicting the best SUSY mass fit and Standard Model limit of only those ATLAS and CMS SUSY searches exhibiting a signal significance of $S/\sqrt{B+1} > 2$. Shown is the best fit benchmark of Ref. [7] at $M_{1/2} = 708$ GeV, with $Br(B^0_S \to \mu^+\mu^-) = 3.5 \times 10^{-9}$, consistent with the recent LHCb measurements of $Br(B^0_S \to \mu^+\mu^-) < 4.5$ (3.8) $\times 10^{-9}$ at 95% (90%) confidence level.

yond our capacity to establish; however, it is becoming increasingly clear that her actions, spanning a broad and non-trivially correlated space of observations, conform remarkably well to the predictions that this model makes. This elegant evasion of myriad potential pitfalls, the rare B-decay limits being but one example among many, serves to highlight the sharp differences in phenomenology that exist between the $\mathcal{F}$-$SU(5)$ framework and the traditional CMSSM/mSUGRA constructions.

Acknowledgments

This research was supported in part by the DOE grant DE-FG03-95-Er-40917 (TL and DVN), by the Natural Science Foundation of China under grant numbers 10821504, 11075194, and 11135003 (TL), by the Mitchell-Heep Chair in High Energy Physics (JAM), and by the Sam Houston State University 2011 Enhancement Research Grant program (JWW). We also thank Sam Houston State University for providing high performance computing resources.

[1] G. Aad et al. (ATLAS Collaboration), "Search for squarks and gluinos with the ATLAS detector in final states with jets and missing transverse momentum using

4.7 fb^{-1} of $\sqrt{s} = 7$ TeV proton-proton collision data," (2012), 1208.0949.

[2] G. Aad et al. (ATLAS Collaboration), "Hunt for new phenomena using large jet multiplicities and missing transverse momentum with ATLAS in 4.7 fb^{-1} of $\sqrt{s} = 7$ TeV proton-proton collisions," JHEP **1207**, 167 (2012), 1206.1760.

[3] ATLAS, "Further search for supersymmetry at $\sqrt{s} = 7$ TeV in final states with jets, missing transverse momentum and one isolated lepton," (2012), ATLAS-CONF-2012-041, URL `https://atlas.web.cern.ch/`.

[4] S. Chatrchyan et al. (CMS Collaboration), "Search for new physics in events with same-sign dileptons and b-tagged jets in pp collisions at $\sqrt{s} = 7$ TeV," JHEP **1208**, 110 (2012), 1205.3933.

[5] S. Chatrchyan et al. (CMS Collaboration), "Search for physics beyond the standard model in events with a Z boson, jets, and missing transverse energy in pp collisions at $\sqrt{s} = 7$ TeV," Phys. Lett. B **716**, 260 (2012), 1204.3774.

[6] S. Chatrchyan et al. (CMS Collaboration), "Search for supersymmetry in hadronic final states using MT2 in *pp* collisions at $\sqrt{s} = 7$ TeV," (2012), 1207.1798.

[7] T. Li, J. A. Maxin, D. V. Nanopoulos, and J. W. Walker, "Chanel $N^o5(\mathrm{fb}^{-1})$: The Sweet Fragrance of SUSY," (2012), 1205.3052.

[8] T. Li, J. A. Maxin, D. V. Nanopoulos, and J. W. Walker, "Non-trivial Supersymmetry Correlations between ATLAS and CMS Observations," (2012), 1206.0293.

[9] T. Li, J. A. Maxin, D. V. Nanopoulos, and J. W. Walker, "The Ultrahigh jet multiplicity signal of stringy no-scale $\mathcal{F}$-$SU(5)$ at the $\sqrt{s} = 7$ TeV LHC," Phys.Rev. **D84**, 076003 (2011), 1103.4160.

[10] T. Li, J. A. Maxin, D. V. Nanopoulos, and J. W. Walker, "The Unification of Dynamical Determination and Bare Minimal Phenomenological Constraints in No-Scale F-SU(5)," Phys.Rev. **D85**, 056007 (2012), 1105.3988.

[11] T. Li, J. A. Maxin, D. V. Nanopoulos, and J. W. Walker, "Prospects for Discovery of Supersymmetric No-Scale F-SU(5) at The Once and Future LHC," Nucl.Phys. **B859**, 96 (2012), 1107.3825.

[12] T. Li, J. A. Maxin, D. V. Nanopoulos, and J. W. Walker, "Has SUSY Gone Undetected in 9-jet Events? A Ten-Fold Enhancement in the LHC Signal Efficiency," (2011), 1108.5169.

[13] T. Li, J. A. Maxin, D. V. Nanopoulos, and J. W. Walker, "Profumo di SUSY: Suggestive Correlations in the ATLAS and CMS High Jet Multiplicity Data," (2011), 1111.4204.

[14] T. Li, J. A. Maxin, D. V. Nanopoulos, and J. W. Walker, "A Higgs Mass Shift to 125 GeV and A Multi-Jet Supersymmetry Signal: Miracle of the Flippons at the $\sqrt{s} = 7$ TeV LHC," Phys.Lett. **B710**, 207 (2012), 1112.3024.

[15] T. Li, J. A. Maxin, D. V. Nanopoulos, and J. W. Walker, "A Multi-Axis Best Fit to the Collider Supersymmetry Search: The Aroma of Stops and Gluinos at the $\sqrt{s} = 7$ TeV LHC," (2012), 1203.1918.

[16] T. Li, J. A. Maxin, D. V. Nanopoulos, and J. W. Walker, "Testing No-Scale $\mathcal{F}$-$SU(5)$: A 125 GeV Higgs Boson and SUSY at the 8 TeV LHC," Phys.Lett. **B In Press** (2012), 1207.1051.

[17] T. Li, J. A. Maxin, D. V. Nanopoulos, and J. W. Walker, "A 125.5 GeV Higgs Boson in $\mathcal{F}$-$SU(5)$: Imminently Observable Proton Decay, A 130 GeV Gamma-ray Line, and SUSY Multijets & Light Stops at the LHC8," (2012), 1208.1999.

[18] C. S. Huang, W. Liao, and Q. S. Yan, "The Promising Process to Distinguish Supersymmetric Models with Large tanβ from the Standard Model: $B \to X_s \mu^+\mu^-$," Phys.Rev. **D59**, 011701 (1999), hep-ph/9803460.

[19] R. L. Arnowitt, B. Dutta, T. Kamon, and M. Tanaka, "Detection of $B_s \to \mu^+\mu^-$ at the Tevatron run II and constraints on the SUSY parameter space," Phys.Lett. **B538**, 121 (2002), hep-ph/0203069.

[20] C. Beskidt, W. de Boer, D. Kazakov, F. Ratnikov, E. Ziebarth, et al., "Constraints from the decay $B_s^0 \to \mu^+\mu^-$ and LHC limits on Supersymmetry," Phys.Lett. **B705**, 493 (2011), 1109.6775.

[21] R. Aaij et al. (LHCb collaboration), "Strong constraints on the rare decays $B_s \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$," Phys.Rev.Lett. **108**, 231801 (2012), 1203.4493.

[22] A. J. Buras, M. V. Carlucci, S. Gori, and G. Isidori, "Higgs-mediated FCNCs: Natural Flavour Conservation vs. Minimal Flavour Violation," JHEP **1010**, 009 (2010), 1005.5310.

[23] A. J. Buras, "Minimal flavour violation and beyond: Towards a flavour code for short distance dynamics," Acta Phys.Polon. **B41**, 2487 (2010), 1012.1447.

[24] D. M. Straub, "Overview of constraints on new physics in rare B decays," (2012), 1205.6094.

[25] S. Chatrchyan et al. (CMS Collaboration), "Search for $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ decays," JHEP **1204**, 033 (2012), 1203.3976.

[26] T. Li, D. V. Nanopoulos, W. Y. Wang, X. C. Wang, and Z. H. Xiong, "Rare B Decays in the Flip SU(5) Model," JHEP **1207**, 190 (2012), 1204.5326.

[27] R. Barate et al. (LEP Working Group for Higgs boson searches), "Search for the standard model Higgs boson at LEP," Phys. Lett. **B565**, 61 (2003), hep-ex/0306033.

[28] W. M. Yao et al. (Particle Data Group), "Review of Particle physics," J. Phys. **G33**, 1 (2006).

[29] E. Komatsu et al. (WMAP), "Seven-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Cosmological Interpretation," Astrophys.J.Suppl. **192**, 18 (2010), 1001.4538.

[30] G. Aad et al. (ATLAS Collaboration), "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC," Phys.Lett. **B716**, 1 (2012), 1207.7214.

[31] S. Chatrchyan et al. (CMS Collaboration), "Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC," Phys.Lett. **B716**, 30 (2012), 1207.7235.

[32] T. Aaltonen et al. (CDF Collaboration, D0 Collaboration), "Evidence for a particle produced in association with weak bosons and decaying to a bottom-antibottom quark pair in Higgs boson searches at the Tevatron," Phys.Rev.Lett. **109**, 071804 (2012), 1207.6436.

[33] G. Belanger, F. Boudjema, A. Pukhov, and A. Semenov, "Dark matter direct detection rate in a generic model with micrOMEGAs2.1," Comput. Phys. Commun. **180**, 747 (2009), 0803.2360.

[34] A. Djouadi, J.-L. Kneur, and G. Moultaka, "SuSpect: A Fortran code for the supersymmetric and Higgs particle spectrum in the MSSM," Comput. Phys. Commun. **176**, 426 (2007), hep-ph/0211331.